Chapter 1
History of Aviation

I may be expediting the attainment of an object that will in time be found of great importance to mankind; so much so, that a new era in society will commence from the moment that aerial navigation is familiarly realized ... I feel perfectly confident, however, that this noble art will soon be brought home to man's convenience and that we shall be able to transport ourselves and our families and their goods and chattels, more securely by air than by water and with a velocity from 20 to 100 miles per hour.

Sir George Cayley (1809)

I have not the smallest molecule of faith in aerial navigation other than ballooning.

Lord Kelvin (1896)

This flight lasted only twelve seconds, but it was nevertheless the first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in full flight, had sailed forward without reduction of speed and had finally landed at a point as high as that from which it started.

Orville Wright (1903)

1.1 Introduction

It is generally recognized that *Wilbur* and *Orville Wright* were the first to perform manned powered flight in 1903. Nevertheless, they were not at all the first to attempt flight. It is an exceptional trait of early aviation history – in contrast to other technical disciplines – that many, during an extended period

of time, tried in vain to conquer the skies. Eventually success was achieved in developing the correct basis and methods enabling the construction of wings capable of sufficient lift and engines capable to provide enough propulsive thrust. Man has been able to navigate through the air in balloons since 1783, though only succeeded with powered flight from 1903; manned space flight has been carried out with the use of rockets since 1961. The origin of these three principles of flight have, however, been public knowledge since the middle ages.

The following overview will start with a brief history of the work performed by pioneers of aviation in the 19th century. Although most of them did not achieve flight, they have contributed to the knowledge and techniques required for manned flight. Thereafter will follow a brief overview of the development of aviation in the 20th century. The emphasis of this chapter is less on events and dates and much more on the factors that have played a roll in the development of the way many pioneers tackled the problems and how they were influenced by others. This overview will also contain certain achievements of Dutch aviation development. Main points of focus will be on the development of aircraft rather than essential components of modern aviation such as airports, navigational and landing aids and air traffic control.

This historical overview is primarily based upon books and articles, as stated in the bibliography at the end of this chapter. These describe early developments in aviation, including the inevitable uncertainties and speculation surrounding the antecedences. The classification of subjects as well as many fragments and information are quoted from a range of authoritative publications by the English historian *C.H. Gibbs-Smith* [7, 8] and by the American aerodynamicist *J.D. Anderson Jr.* [1]. Modern aircraft development during the second half of the 20th century is touched upon somewhat superficially; a recent book authored by *R. Whitford* [21] is recommended for more detailed information. Chapter 5 contains an historical overview of aircraft engine development, further historical notes will also be found in several other chapters. The majority of technical terms used in this chapter will not be elaborated on; terminology which is printed in italics can be traced in the index for further use in later chapters, where explanations can be found.

1.2 Early history and the invention of ballooning

Imitating the flight of birds

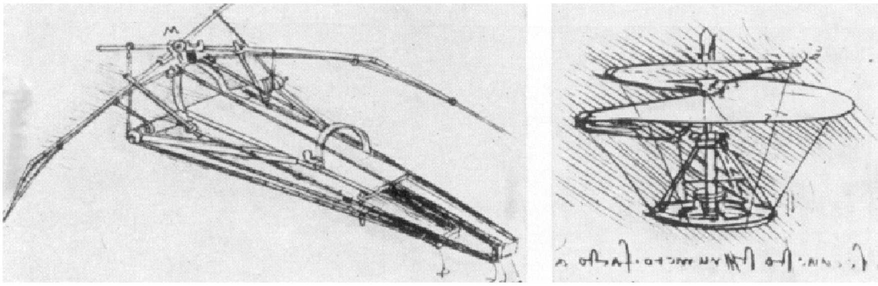
Throughout history, man has aspired to be able to leave mother earth and take off as free as a bird, even today with flight already accomplished on a regular basis, it continues to appear in the dreams of many. The ability to fly is therefore also embedded in the mythological stories from the antiquity, when man realized his envy of birds and attempted to imitate their flight. The following Greek myth strongly symbolizes the challenging and risky character of flight:

> *Daedalus managed to escape out of the Labyrinth – after all, he was the one to have built it and knew his way around. Daedalus decided that he and his son Icarus had to leave Crete and get away from Minos, before he brought them harm. However, Minos controlled the sea around Crete and there was no escape route. Daedalus realized that the only way out was by air. To escape, Daedalus built wings for himself and Icarus, fashioned with feathers held together with wax. Daedalus warned his son not to fly too close to the sun, as it would melt his wings and not too close to the sea, as it would dampen them and make it hard to fly. They successfully flew from Crete, but Icarus grew exhilarated by the thrill of flying and began getting careless. Flying too close to the sun god Helios, the wax holding together his wings melted from the heat and he fell to his death, drowning in the sea.*

The classical myth of Icarus has become well known, even though there are many other illustrations of attempts to fly dating back to ancient times and the middle ages.[1] There were many (regularly failing) flight attempts undertaken – sometimes at the costs of broken limbs or even life – without real progress being achieved. Nevertheless, certain artifacts from the distant past are known that are founded on the principles of flight, such as the (aerodynamic stabilizing finned) rocket, the boomerang invented by Australian aboriginals, the (toy) glider and the *propeller*.[2] Kites may be considered to be the predecessor of the aeroplane, because they are heavier-than-air and take to the air (in the wind). Many centuries before Christ, they were in existence in China and other far-eastern countries, where they have maintained

[1] The painter Hieronymus Bosch (ca. 1450–1516), depicted many flying people and animals and even flying ships in his paintings.

[2] In the early days a propeller was referred to as an airscrew.

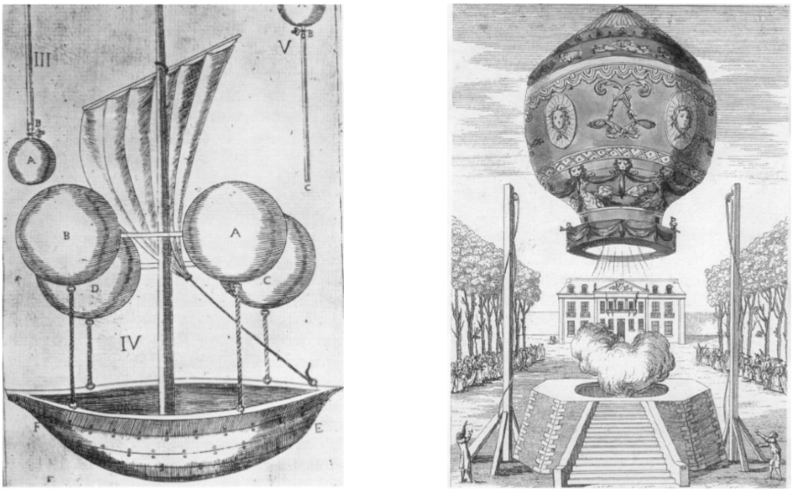


Prone-type ornithopter Helicopter

Figure 1.1 A few of Leonardo da Vinci's sketches of aircraft (1485 to 1490).

popularity. From the 15th century, kites could also be found in Europe. They were used to perform atmospheric measurements during the 18th century, while *Benjamin Franklin* (1706–1790) went on in 1752, using kites, to carry out experiments with lightning. Another example of Chinese origin is the propeller which was widely used – in a somewhat primitive form – as a windmill. Active propellers were first used in Europe in the fourteenth century in toys which were spun by the hands. In fact these were models of a *rotor*, of which examples can be found in paintings dating back to that time.

It is not surprising that the majority of early flight initiatives were based on the flight of birds. This stimulated *ornithopter* designs, flying machines with flapping (muscular-powered) wings. The well-known illustrations by *Leonardo da Vinci* (1452–1519) show the early mind-set (Figure 1.1). The brilliant Florentinian did not only conceive *ornithopters*, but also produced the first sketches of a *parachute* and a *rotor*. It is unlikely that these drawings ever led to a full-scale model, as da Vinci must have anticipated with his extensive knowledge of the human body that its muscles could never be sufficiently powerful to make sustained flight in such a way. The English physicist *Robert Hooke* (1635–1703), contemporary and friend of *Isaac Newton* (1642–1727), experimented without success with ornithopter-type models. Outside of these attempts, there was little rigorous thought towards practical aviation before the end of the 18th century. Because da Vinci's work was not unveiled until 1795, it could not have had much influence on other researchers at the time.



(a) Francesco Lana-Terzi's idea of a "Flying Ship" (1670)

(b) First Montgolfier hot-air balloon flight by Pilâtre de Rozier and François Laurent (1783)

Figure 1.2 The beginning of lighter-than-air (static) aviation.

First balloonists

Within the field of *static aviation* – that is, aircraft lighter-than-air – there is an exceptional design dating from 1670 of an *airship* (in the most literal sense of the word) by the Portuguese monk and inventor *Francesco Lana-Terzi*; see Figure 1.2(a). He supposed that on the basis of *Archimedes' law* it should be possible to let a set of copper spheres rise – he chose a diameter of 6 m – when pumping out the air. His idea was inspired by the invention of the air pump in 1650. Lana-Terzi thought it may be possible to steer the vessel using a sail, a presumption which was obviously unfounded. He did however realize that the paper-thin walls would not be able to withstand the pressure. He quickly concluded "that mankind had been saved from this threatening invention, which may lead to destructive implementations (such as war)" and therefore could satisfy his shortcomings to a certain degree.

The first successful flight by *hot-air balloon* took place at the end of the 18th century. The Frenchman *Joseph Montgolfier* (1740–1810) and his brother *Jacques* (1745–1799) were the proprietors of a paper mill. They succeeded in fabricating a linen strengthened paper balloon with a diameter of 15 m containing 2,200 m^3 of hot air. The straw-fire heated air they called "Montgolfier gas", possibly to protect their invention against imita-

tion. After firstly testing the balloon with a sheep, a rooster and a duck on board, the first manned test flight was performed in Paris on November 21st, 1783, by *Pilâtre de Rozier* and *François Laurent*; see Figure 1.2(b). During this flight, which lasted 25 minutes, they covered approximately 12 km and they even managed to land safely. The second test flight took place ten days later and also in Paris, though this time with a *hydrogen balloon*.[3] It was the noted physicist *J.A.C. Charles* (1746–1823) – the originator of the gas law in physics – and the brothers Robert, who supplied the rubber-impregnated cover. Pilâtre de Rozier died two years later in an explosion while carrying out experiments in which he tried to combine the lifting capacity of hydrogen with altitude adjustments by burner-heated air.

Man had now succeeded in taking flight to great heights without too much danger, suspended under a balloon lifted by hot air, hydrogen or methane gas. Balloons were first used by physicists – and are still used today by meteorologists and astronomers – when J. Jeffries and J.P. Blanchard in 1784 did scientific observations above London. The same pair were the first to cross the Channel by flight in 1785. J.A.C. Charles among others used balloons to measure temperature variations with altitude in the atmosphere. The first observations with cable-attached balloons were carried out by the French army in 1797, while *Jacques Garnerin* (1770–1825) was the first to perform successful parachute jumps from a hot-air balloon in 1797.

One of the main objections to balloon flight is that is was practically impossible to steer the balloon in the air. This was the main reason leading to the discovery of the *propulsion* principle for flight. Merely a decade after the first flight, there were many proposals for controlling the direction of flight. The ideas varied from propellers – the first attempt by J.P. Blanchard failed in 1789 – to propulsion through hot air jets, steam or gunpowder. The proposal by Joseph Montgolfier to steer by means of an adjustable opening in the side of the balloon – opposite to the desired direction of flight – was an expression of the *reaction principle*. However, the internal pressure in the balloon was insufficient to make it possible in practice. It was also recognized that the considerable air drag caused by the large balloon size could be significantly reduced by using a slender cigar-like shape instead. Hence the principle of *streamlining* was introduced, leading to the invention of the *airship* concept.

[3] Hydrogen gas was first produced by H. Cavendish in 1766.

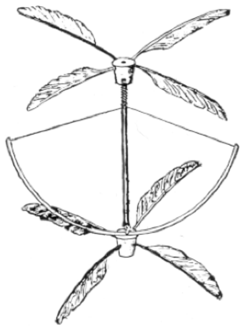
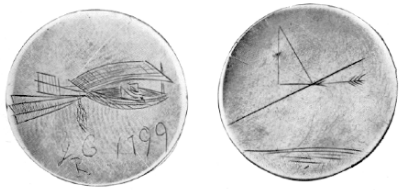


Figure 1.3 Cayley's bow-powered rotor, a variation to the model by Launoy and Bienvenue.



(a) The silver disk, dated 1799, with an engraved diagram showing the forces of lift, drag and thrust

(b) Sketch of the first feasible design for a model glider in history, made and flown in 1804

Figure 1.4 George Cayley's "heavier-than-air" aircraft concept, the true beginning of mechanical aviation.

First rotors

As already mentioned, the principle of a *rotor* was proposed by *Leonardo da Vinci* around 1500. It was the mathematician Paucton who realized the possibility of creating a lifting force by means of a rotor in 1768. The French scholar Launoy and his assistant Bienvenue took the idea to the next level in 1784 with the assembly of a model with two rotors, placed one above the other and spinning in the opposite directions. The rotors were driven by a bow and had blades made of turkey feathers. *George Cayley* built a variation to this model in 1796 (Figure 1.3), the design was published in 1809 and gained wide and lasting attention. The prototype can be seen as the predecessor to the *helicopter*.

1.3 The period between 1799 and 1870

George Cayley

The modern aeroplane design takes its origins from a design in 1799 by the Englishman (Sir) *George Cayley* (1773–1857). According to his research in the area of bird flight and his knowledge of the human body, Cayley determined that the flapping-wing principle applied in an *ornithopter* must be replaced by a fixed wing to be able to generate sufficient *lift*. To compensate for air drag he chose a separate source of propulsion. He proposed to stabilize the flying machine by means of a cruciform set of horizontal and vertical tail surfaces. Cayley engraved sketches of his ideas onto both sides of a silver disc which is in the collection of the British Science Museum; see Figure 1.4(a). The first sketch shows that he planned to create forward thrust by means of primitive flapping blades. On the reverse side, the arrow depicts the oncoming flow at an *angle of attack* to the wing cross section. The force diagram shows the resultant air force resolved in its two components *lift* perpendicular and *drag* parallel to the flow. Cayley's aircraft would become the first real concept of modern *fixed-wing aircraft*, which would make the principle of mechanical flight possible (with heavier-than-air aircraft).

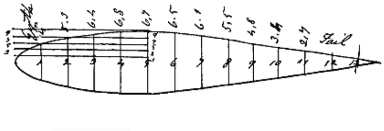
In 1804, Cayley carried out experiments using a whirling-arm mechanism[4] upon which he fixed a model wing. In the same year he built and tested the first of several glider models in which he incorporated his new ideas on flight; see Figure 1.4(b). The model was approximately a metre in length and was equipped with a fixed wing, adjustable tailplane and ballast in the nose to adjust the *centre of gravity* to the correct location. Cayley published further details in 1809 and 1810 in a document entitled "On Aerial Navigation".[5] This was the first publication on theoretical and applied *aerodynamics*. The main points of many important scientific foundations of conventional fixed-wing aircraft flight are established in this monumental piece of work.

Cayley was a versatile researcher, designer and later on also a politician. His scientific activities were broad, covering his observations and ideas on the flight of birds, ornithopters, aerodynamically stabilized projectiles, aerofoils, aircraft undercarriages, box structures, *streamline* shapes, airships,

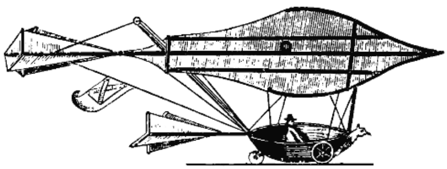
---

[4] The whirling-arm which was used to measure the air drag of moving objects such as bullets is an invention of the Englishman *Benjamin Robins* (1707–1751). It was the only way of drag measurement at that time since the *wind tunnel* was not invented until the second half of the 19th century.

[5] The term "aerial navigation" indicated aviation in general rather than navigation, at the time.



(a) Streamline body (1809)



(b) Monoplane manned glider (1852)

Figure 1.5 Two remarkable designs by George Cayley.

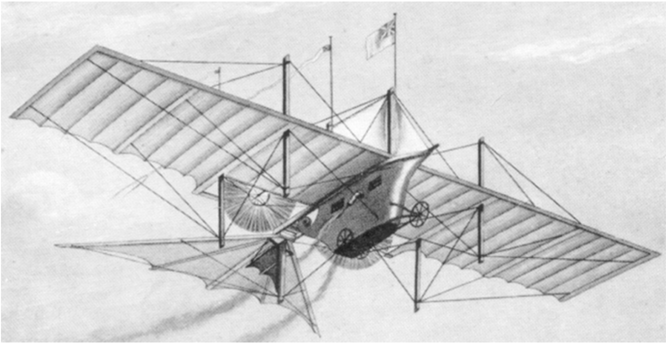
gliders, steerable parachutes, flight controls and other aspects of aviation. Cayley was also active in other fields, such as the design of *internal combustion* engines, and he is credited with the invention of the hot-air engine, the spoked wheel and the caterpillar tracked land vehicle. It was his broad interest in various disciplines that in all probability kept him from further development of aeroplane wings after 1810. Despite this he continued with static aviation, but this was impeded due to the lack of powerful and lightweight engines until the end of the 19th century. He made a number of significant recommendations in relation to the *streamlining* of airships in particular, as well as the proposal to derive a low-drag aerofoil from the shape of a trout; see Figure 1.5(a). Incidentally, during Cayley's life the airship remained popular and there were a number of historical flights carried out, including a flight from London to Weilburg in Germany in 1836 over a distance of some 770 km. Cayley also published an improved design for a propeller-driven airship in 1816.

Cayley resumed his aeroplane design activities during the period between 1848 and 1853. In 1849 he built a full-scale *glider*[6] with three sets of wings placed above each other (triplane), which was firmly claimed to have been flown with a young boy. It is a real possibility that a few years later Cayley's coachman carried out a flight in a similar plane, gliding to a rather rough landing[7] An article about the first design of a manned glider (Figure 1.5b), appeared in 1852 in the renowned *Mechanics Magazine*. It consisted of

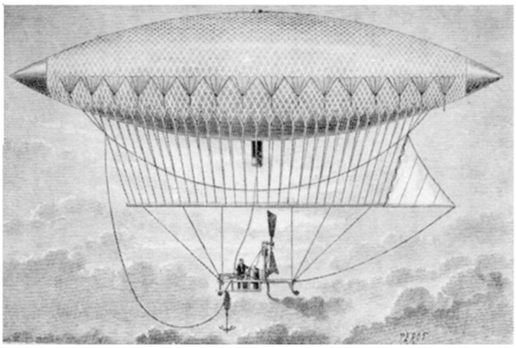
- a wing set with an incidence to the main body and *dihedral* for lateral stability,
- an adjustable *empennage*,
- pilot-controlled *elevators* and a *rudder*,

[6] A glider is an aircraft (model) that flies without the help of an engine. Present-day gliders can make sustained flights and are usually called sailplanes.

[7] After the flight it was reported that the coachman protested: "Please, Sir George, I wish to give notice, I was hired to drive and not to fly".



(a) W.S. Henson's prophetic design for an "Aerial Steam Carriage" (1842–43)



(b) First feasible airship, by H. Giffard (1852)

Figure 1.6 Much-discussed steam-driven aircraft designs dating from the middle of the 19th century.

- a fuselage in the form of a stagecoach, with a seat for the pilot and three wheels,
- a frame of steal tubes.

A similar contraption would be built half a century later by the Wright brothers. Cayley's inventions were, however, quickly forgotten after his death and were not fully rediscovered for another century [7], and therefore did not have much influence on the development of aircraft.

First powered models

In 1843, *W.S. Henson* (1812–1888) published an exceptional and visionary design for an "Aerial Steam Carriage", a *monoplane* equipped with a rec-

tangular wing with separate upper and lower skins. This was powered by two (steam driven) *propellers* and had a three-wheel undercarriage; see Figure 1.6(a). The illustrations were spread in large numbers and had a great influence on later pioneers. Henson completed a prototype in 1857, though it never accomplished a flight of any significant duration.

The first aircraft designs appearing in mainland Europe in the 1850s were probably inspired by Henson. Frenchman F. du Temple built a refined, clockwork-driven model in 1857 and 1858. This was the first flying model of a powered aircraft, however the later full-scale aircraft never managed flight. In the the same period, it was *F.H. Wenham* (1824–1908) in England, who carried out pioneering research on designs with a set of large-span wings placed above one another. He managed to prove that, for a small incidence, cambered wings accredit most of their lift to the nose and that a high-aspect ratio wing[8] generates lift with a low drag penalty.

In the same decade (1850–1860), the French engineer *Henry Giffard* carried out the first successful attempts to fly with a manoeuvrable *airship*; see Figure 1.6(b). Powered by a steam engine-driven propeller it only achieved a top speed of 8 km/h. A later version had a capacity of 50 people and gave some 35,000 people their first flight in Paris during the aviation salon of 1878. It is also worth mentioning that the first promising aircraft (gas) engine was developed by the Belgian-French engineer *J.E. Lenoir* (1822–1900) in 1860.

In the 1860s a new generation of pioneers entered the scene and the first professional societies aimed at aviation were initiated. In France the Société de l'Aviation was founded with the main purpose of stimulating the construction of aircraft for mechanical flight. An English counterpart, the Aeronautical Society – now the Royal Aeronautical Society – followed in 1868, organizing the first world aircraft exhibition at Crystal Palace, London. This is where *J. Stringfellow* presented a steam-powered triplane, which indeed did not preform any independent flight, but attracted much attention and led to the much applied concept of multiple wings (bi- and triplanes). Englishmen Butler and Edwards succeeded in receiving a patent in 1867 for the use of rocket-driven propellers on a *delta wing* aircraft.

[8] This implies that the wing has a long distance between the tips compared to its chord length, to which Wenham referred as a "long and narrow wing".

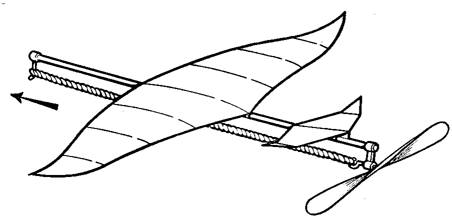


Figure 1.7 Alphonse Pénaud's stable model called a "planophore", with a pusher propeller driven by twisted strands of rubber (1871).

1.4 The decades between 1870 and 1890

Various inventions

The years following 1870 were characterized by the arrival of rubber-powered model aircraft. The Frenchman *Alphonse Pénaud* (1850–1880) first displayed this principle with his "planophore" (Figure 1.7). Even though Pénaud was not familiar with Cayley's work, he incorporated the concept of inherent stability by using a negative *angle of incidence* for the horizontal tailplane. Pénaud also used a wing with *dihedral*, having its tips raised above the root. Equally remarkable was Pénaud's patent for a full-size amphibious flying machine, designed with the help of his assistant, P. Gauchot. This was equipped with

- a wing with elliptical planform, *cambered aerofoils*, small dihedral and separate upper and lower skins,
- two tractor propellers rotating in opposite directions to cancel their torque effect,
- two *elevators* and a vertical fin with *rudder*, activated by a *control column*,
- a *cockpit* with a glass dome, equipped with various instruments, such as a compass and a barometer for measuring altitude,
- a retractable undercarriage with pneumatic shock absorbers and wheels for *take-off* and *landing*. Pénaud was far before his time with another patent for a *propeller* with adjustable blades. Through his inventions, Pénaud may also be considered a 19th century co-founder of modern aviation alongside Cayley.

The following events also took place during the 1870s.
1871: First use of the *wind tunnel*, by the Englishmen *F.H. Wenham* and J. Browning.

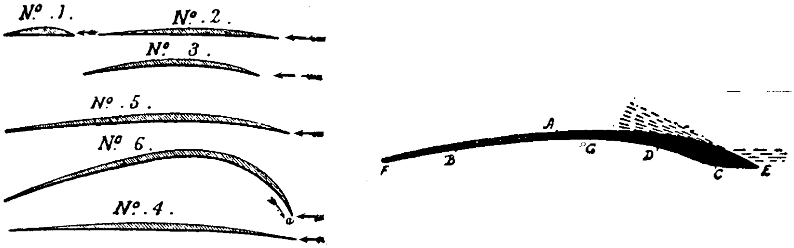


Figure 1.8 Phillips patent sketches of his *cambered aerofoil* shapes (1884 and 1891).

1873/74: Experiments with tandem-winged models in Britain, by D.S. Brown.
1874: Manned aeroplane with a hot-air engine, designed and built by the Frenchman F. du Temple. This became the first craft to make a power-assisted but unsustained flight off an inclined plane.
1875: Successful demonstration of a large tandem-winged model aircraft, by the Englishman T. Moy.
1879: Monoplane model powered by a compressed air engine, designed by the Frenchman V. Tatin.

During this period hot-air balloons gained an improved reputation due to the assistance they provided in evacuating refugees and the transportation of postage and homing pigeons to and from occupied Paris (winter of 1870/71). Without the realization of the pioneers of aviation, the future of aircraft engines took a large step forward when German engineer *Nikolaus August Otto* succeeded in building a four-stroke *petrol engine* in 1876. Another German engineer, K.F. Benz, built the first car with a *petrol engine* in 1885, though this achievement was quickly overshadowed the following year by G. Daimler's car, which made use of an improved *Otto engine*. H. Wölfert was the first to utilize such an engine in his prototype airship (1888).

Powered aircraft came much closer to their realization with the arrival of the four-stroke engine. The years following 1880 were nevertheless not the most productive years in aviation history, though one development of significance was achieved in this period, namely the patent obtained by Englishman *Horatio Phillips* for his cambered *aerofoils* (Figure 1.8). Phillips was the first to show that such an aerofoil shape resulted in better lifting capability due to the suction on the cambered upper surface, based on his observation that the lower surface contributed far less to the lift. Further aircraft designs were

greatly influenced by this important discovery of a property that Cayley anticipated, but had never been able to prove.

Chauffeurs versus airmen

Approaching the 1890s, the well-informed pioneers of the time realized that the eventual accomplishment of flight would soon become reality. The methods used in the first flight attempts were categorized into two groups by *C.H. Gibbs-Smith*, as follows:

1. The chauffeurs saw flying as a continuation of driving a car and therefore put their faith in the construction of an aircraft that could fly straight off. Their presumption that flying an aeroplane would be an easy task as long as there was enough thrust to keep it off the ground was, however, an illusion.
2. The airmen realized that as soon as the aircraft took off it no longer had contact with the ground. To maintain the feeling of control over the aircraft, an airman would need to become at one with it. These pioneers would undertake test glides in order to develop this feeling before attempting a flight with a powered plane.

The French electro-technician *Clément Ader* was a typical example of a chauffeur. He attempted a flight with his steam engine-powered propeller aeroplane Eôle in 1890. The painstakingly designed construction barely made it off the ground and the primitive machine was completely uncontrollable in the air, covering a distance of no more than a few tens of metres. Ader made another attempt in 1897 with the Avion III, though this attempt had no further influence on the development of aviation. The American based Russian *Hiram Maxim* – he was the inventor of the first automatic machine gun – also belonged to the chauffeurs. Maxim built a huge and expensive steam driven propeller biplane.[9] Its best test flight was in 1894, when the plane briefly left the rails from which it started. This attempt also failed to become an autonomic and controlled flight.

[9] A biplane is an aeroplane with one wing arranged more or less above the other.

1.5 From 1890 until the Wright Flyer III

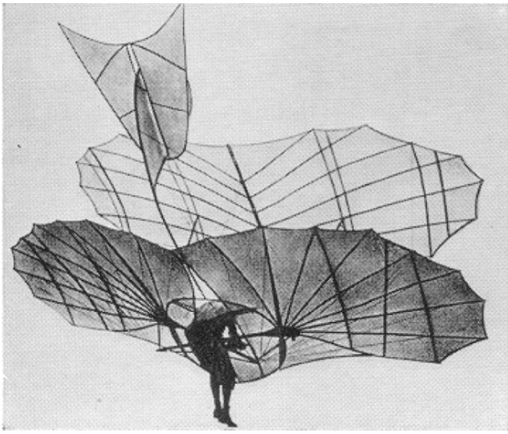
Otto Lilienthal

The most important aviation pioneer from the second half of the 19th century was a true airman, whose work with gliders helped in the last phase of conquering the skies. This was the German engineer *Otto Lilienthal* (1848–1896), who had concentrated much of his attention on the construction of an ornithopter since 1862. Just as Cayley, he discovered that flight does not entirely depend upon the flapping of wings and that birds use this primarily for propulsion. For the next twenty years he worked with his brother Gustav on *aerodynamics* and *flight mechanics*. Their findings were published in the classical book "Der Vogelflug als Grundlage der Fliegekunst" (1889), which contributed greatly to the eventual solution of the quest for flight.

Between 1891 and 1896 the Lilienthal brothers constructed a range of *hang gliders* on which Otto would hang by his arms and would manoeuvre the glider by moving his body.[10] This resulted in a *centre of gravity* shift, offering a reasonable amount of *pitch* and *lateral control*. The Lilienthals constructed their gliders out of bamboo and willow wood, applying cambered aerofoils and horizontal and vertical tail surfaces. Otto Lilienthal attempted to solve the problem of powered flight by means of a carbon dioxide engine moving the wing tips up and down. His brother Gustav also spent decades experimenting with *ornithopters* without success. Apparently the brothers could not completely liberate themselves from aiming at the imitation of bird flight.

Otto Lilienthal was the first in history to perform controlled gliding flights. Taking off from various hills in the region of Berlin and from a specially constructed ramp, he performed approximately 2,500 glides in a period of five years over distances of a few hundred metres, with a total air time of about five hours. Lilienthal's far-reaching influence was reinforced by the publication of clear photos of his flights; see Figure 1.9(a). These photos and articles originally attracted the Wright brothers to devote themselves to the development of aviation. Lilienthal had succeeded in fulfilling many of his predecessors' aspirations and was preparing to commence with powered flight when disaster struck. During his final flight (on August 9th, 1896) his glider was hit by a thermal gust, bringing it to a complete stop. It is believed that the glider became *stalled* and uncontrollable. Lilienthal crashed from a height of 15 m and broke his spine, leading to his death a day later.

[10] Hang gliders are used today in recreational aviation.



(a) Otto Lilienthal flying one of this biplane gliders (1895 or 1896)

(b) Octave Chanute's biplane glider (1896)

Figure 1.9 The first hang gliders.

Other gliding pioneers

Lilienthal had several followers, even if they were not in his own country. One of them was Scottish engineer *P.S. Pilcher*. He also made good progress in 1896 with building and flying hang gliders and in 1899 he was assembling an engine for his own designed powered aircraft, the Hawk. He died, however, in the same year as a result of a crash caused by a broken tail boom.

The French-born and American resident *Octave Chanute* (1832–1910) was a civil engineer who became interested in mechanical flight in 1875. Since then he accumulated all the information he could find on aviation

and wrote the detailed and summarizing classical book "Progress in flying machines". Chanute was an airman. He successfully built and flew a hang glider, Figure 1.9(b), in the manner of Lilienthal in 1896, though he used the more effective Pratt truss method method of structural rigging. The wings and tailplane of his glider were stiffened similar to the box-kite concept, invented in 1893 be Australian *Lawrence Hargrave*, which would eventually also be used by the Wright brothers. Chanute would later be heavily involved in the revival of aviation in Europe. In 1903 he visited France, where he gave a number of lectures in which he dispensed much information on the gliding flights of the Wright brothers. This led to a revival in European aviation.

Langley's aerodrome

The famous astronomer *Samuel Pierpont Langley* (1834–1906) is placed among the chauffeurs, because he attempted to launch a powered manned aircraft without having any flying experience. In 1896 he succeeded in making a series of rubber- and steam-driven models[11] perform short flights after many failed attempts. Shortly thereafter he decided to cease with further research, though the U.S. Ministry of Defence later convinced him to construct a manned aircraft. In August 1903, Langley succeeded with the flight of a quarter-scale model powered by a 2.4 kW *petrol engine*. Only a few months later he had built the full-size version, which was also equipped with *tandem wings*. Propulsion was provided by an ingenious *radial engine* developed by his assistant *C.M. Manly*. The craft was intended to be launched by means of a catapult from a houseboat on the river Potomac, on October 7th and December 8th, 1903. The aerodrome would be flown by Manly, but during both flight attempts it was fouled by the launching mechanism and fell into the river. Manly was fished out, unhurt. After the last failed attempt, nine days before Orville Wright's first powered flight, the War Department gave up, stating that "we are still far from the ultimate goal of human flight". What was left of Langley's aerodrome was demolished.[12]

---

[11] Langley's flying machines bore the name "aerodrome" after the Greek word aerodromo, air runner.

[12] In 1914 the American G. Curtiss modified the design of Langley's aircraft and re-attempted flight, though he also failed to make the aircraft manoeuvrable. Being a competitor of the Wright brothers he had hoped to prove that – with an improved launching provision – the aerodrome concept had the capability to beat the first powered flight before the Wrights succeeded.

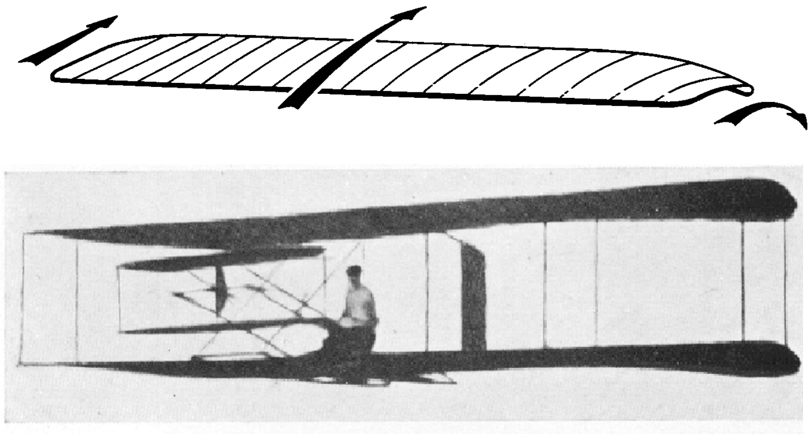


Figure 1.10 The Wright brothers' concept of wing-warping, invented in 1899, which can be seen here in the Flyer Type A.

The Wright brothers

The two men who eventually, definitively and unequivocally, conquered the skies were the American brothers *Wilbur* (1867–1912) and *Orville Wright* (1871–1948). They grew up in Dayton (Ohio) and started out building, repairing and selling bicycles in 1892. Lilienthal's achievements caught their attention and started an interest for aviation which would lead to them becoming experts in the construction of aircraft, aerodynamics and piloting. Gradually and with strategic planning, they aimed to achieve controlled flight of gliders before attempting powered flight, which proves them to be the perfect example of airmen.

Glider development

The Wright brothers were the first to pursue the concept of *lateral control*. They discovered that buzzards manoeuvered by *twisting* their wing tips. Wilbur came up with a roll control method in 1899, using cables to twist the outer wing, known as *wing warping*. The concept was promptly utilized on an unmanned and two manned *biplane* type gliders (Figure 1.10). In view of Lilienthal's accident, the Wrights did not place the *elevator* at the rear end of the aircraft, but at the front, as they expected it to cushion a *stall*, after which the aircraft and its pilot could "parachute" to the ground. At that time this

was a very unconventional configuration and was named a *canard*, perhaps after the French term “C’est un canard”, which some Frenchmen mockingly bantered at Wright’s plane.

After test flights of the first gliders (no. 1 in 1900 and no. 2 in 1901) were performed on the sandbanks of Kill Devil, south of Kitty Hawk in North Carolina, the Wright brothers were convinced that the data in Lilienthal’s book on *aerodynamics* were of no practical use to them. By means of a self-built wind tunnel, with dimensions of 10 $\times$ 10 cm in cross section and 2 m in length, they were able to test some 200 different models with various wing and aerofoil shapes. This research resulted in the construction of the greatly improved glider no. 3 (1902). It is a prime example of the approach which would later be taken to develop aircraft designs by means of accurate computation and experiments. The foremost difficulty in obtaining a controllable aircraft which the Wrights needed to overcome was the problem of an *adverse yawing* motion in *turning flight*, that is, flying a circle. This was caused by the wing warping, leading to increased drag of the wing tip on the external side of the turn. The first two gliders were equipped with two (fixed) vertical tails. However, to compensate for the undesirable yawing moment due to wing warping and for obtaining directional control in a stall, these were replaced by a single controllable *rudder* on the third glider.

With the use of wing warping by means of a single control lever linked to the rudder – another lever was used for operating the elevator – the Wrights had effectively solved the problem of three-axis control for the first time in history. The patents for this concept was widely published from 1906 onward in Europe as well as in the USA. However, this led to many contesting parties of the Wrights’ solutions in claiming that various ideas were previously invented. This led in turn to a number of lengthy law suits, resulting in a great deal of bother for the brothers.

The first powered flight in history

Glider no. 3 would perform some thousand flights, with the longest lasting 26 seconds. This aircraft formed the baseline for the first powered aircraft, which became famously known by the name of Flyer I (Figure 1.11). The Flyer was also a biplane, but its wings had an *aspect ratio* (span/chord) of six, twice that of glider no. 3, which resulted in improved flight performance. Just as the previous gliders, the Flyer also had its elevator in front and the rudder to the rear of the wing – the *canard* configuration. Flyer I had not only three-axis control, it was also equipped with two other features exclu-

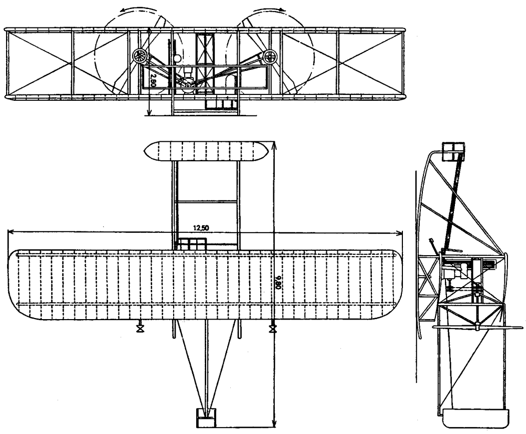


Figure 1.11 Three-view drawing of the Wright Flyer I.

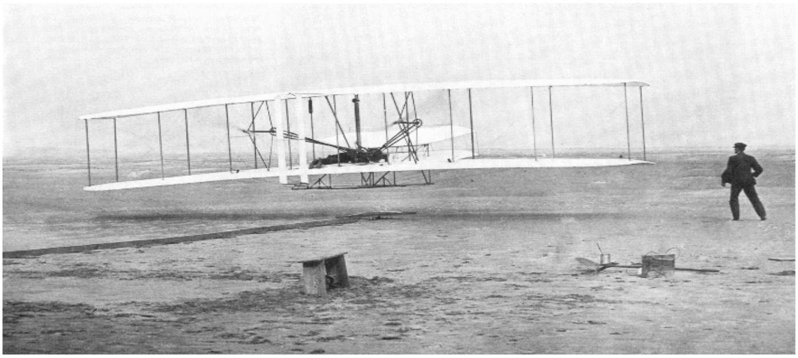


Figure 1.12 The first successful autonomous powered flight in history by Orville Wright with the Flyer I on December 17th, 1903.

sively designed by the brothers: a 9 kW gasoline-fuelled engine and two propellers driven by bicycle-type chains near the wing trailing edges. This type of transmission took care of the high rate of engine revolutions to be tuned to the lower propeller speed, resulting in high propeller thrust. The chains were crossed over on one side to enable the propellers to turn in opposite directions. *Propeller efficiency* was recorded at (a remarkably high) 70%. The uncomfortable bent-over pilot's position left of the engine would be adjusted by including a seat a few years later.

On December 17th, 1903, the Wrights performed the first successful powered flight with the Flyer I, taking off from an 18 m long rail (Figure 1.12). The first of four flights (by Orville) lasted twelve seconds, the fourth flight (by Wilbur) lasted 59 seconds, while a ground distance of 260 m was cov-

ered. This flight was, however, performed into a breeze and the air distance is estimated at more than 800 m. Although the flight heralds the start of a new era of aviation, it did not immediately make the headlines. During the following year, the Wrights fine-tuned their invention in the construction of Flyer II (1904) and Flyer III (1905). The propellers were improved along with small adjustments to the flight control through changes to the wing *camber*, the tailplane and the control mechanism. The Wights succeeded in flying horizontal circular and figure-eight courses and could stay in the air for half an hour; the flight *endurance* was only limited by the amount of available fuel. Flyer III was the first practical (powered) aeroplane in history and its performance was matched by no other plane until 1909, apart from further developments by the Wright brothers themselves.

In 1906 and 1907 there would be no more flying, rather six new engines would be built and a new two-person version of Flyer III with a 30 kW engine: the standard Wright Type A. This aircraft was demonstrated to the American public in 1908 as well as in France and attracted a wave of publicity and enthusiasm. On December 31st, 1908, Wilbur Wright flew for two hours and twenty minutes over a distance of 125 km, with which he won a large cash prize. This saw the Wrights securely established as great pioneers of powered flight. Unfortunately, the Flyer Type A crashed in December of that year due to a broken propeller, during which Orville was injured and his passenger died. Nevertheless, the American Army ordered the first planes as the Wright brothers found themselves at the height of their fame between 1908 and 1910.

Although the Flyer was well manoeuvrable, it suffered from a lack of *longitudinal stability* due to the *elevator* location in the front of the wing. European longitudinally stable "self-flying planes" began to develop quickly and before long took the upper hand in comparison to the Flyer. Wilbur Wright passed away in 1912 and from then on Orville Wright faded into the background, though he remained active in the field of aviation. He still contributed with inventions such as the *split flap*.

Aviation in Europe

Despite attempts by the Frenchman F. Ferber to construct imitations of Lilienthal's gliders after his death, the field of mechanical aviation became somewhat inactive in Europe. In 1902 Ferber imitated the Wrights' aircraft, using Chanute's information, but without concentrating adequately on

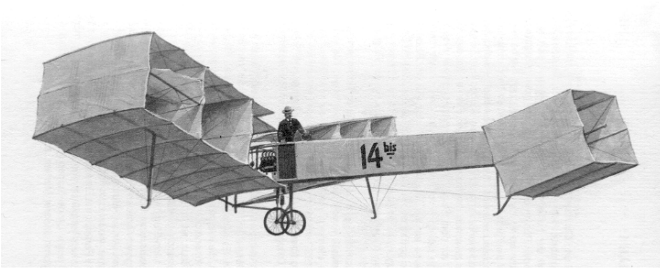


Figure 1.13 Santos Dumont's Bagatelle, in which the first powered flight in Europe was performed (1906). The direction of flight is to the right.

certain important details. Nevertheless, the revival of European aviation in 1904 and 1905 was largely thanks to Ferber's primitive copies and to those by E. Archdeacon and R. Esnault-Pelterie, who were equally inspired by Chanute. Ferber's contribution was not unimportant with the addition of a fixed vertical *fin* to the Wright design. This resulted in the concept of aircraft with *directional stability* in Europe and Ferber's initiative formed the start of practical aeroplanes that were stable, even with free controls.

In 1903 the Frenchman L. Levavasseur succeeded in building the water-cooled petrol engine Antoinette, with a mass of 50 kg, supplying 18 kW of power, which was used for various flight attempts. In 1905, G. Voisin produced, with E. Archdeacon's and L. Blériot's assistance, two floating gliders and launched these from a motorboat on the Seine. Though both attempts failed in proper flight, these aircraft were seen as the predecessors of the European stable *biplanes* that would later be constructed. The development thereafter stagnated somewhat until Chanute published detailed reports about the Wrights' flights. From then on aviation research and development took a rapid upturn.

1.6 European aviation between 1906 and 1918

First powered flights

The first powered flight in Europe was performed by the Brazilian Santos Dumont on October 23rd, 1906 in his 14-bis Bagatelle, which flew 220 m in about 21 seconds (Figure 1.13). The first autonomous flight lasting longer than a minute was made by Henri Farman in 1907, but it took until 1908

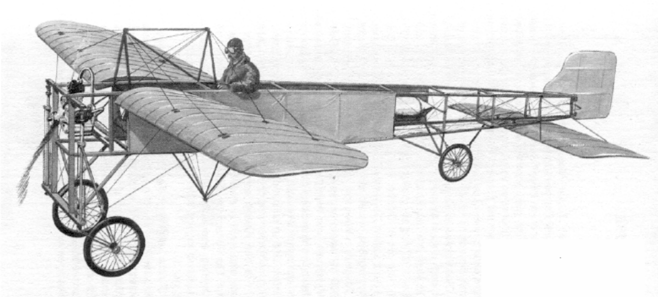


Figure 1.14 Blériot's monoplane No XI, in which he crossed the Channel on July 25th, 1909.

before there was any real talk of progress, when Wilbur Wright performed a range of demonstration flights in Europe. The development of aviation thereafter progressed rapidly, with planes built by men such as H. Farman, A. Voisin and L. Blériot in France and A.V. Roe in England, amply managing to compete with the flight characteristics of those of the Wright Flyer A.

The concept of powered flight invented by the Wright brothers was partially adopted and improved upon in Europe. The Flyers were well manoeuvrable but lacking in stability. The front elevator caused a considerable amount of longitudinal instability[13] and most of the European designers made use of an aft-located horizontal tailplane with elevator, the Farman-Voisin biplane in 1907 forming an exception. The vertical *fin* with a rudder is also of European origin. Instead of wing-warping, most European pioneers used *ailerons*. The then conventional system using a *control stick*[14] for *longitudinal* as well as *lateral control* was first introduced in Europe by *Louis Blériot* and in the USA by *Glenn Curtiss*. Contrary to the Wrights,[15] most of the pioneers used wheeled undercarriages.

Flights performed in Europe started lasting longer and began to break aviation records. Louis Blériot was the first to cross the English Channel in 1909, flying a distance of 40 km (Figure 1.14). In doing this he showed that flight could be a serious competitor with shipping, something that would not

[13] A canard configuration is not by definition unstable. From 1970 onwards designers – among them was the American E.L. (Bert) Rutan – have managed to use this concept on light aircraft while maintaining stability.

[14] A control column with a wheel was later introduced on larger aircraft.

[15] Although the Wrights were bicycle builders, they chose not to use wheels but runners combined with a launching rail. After successful flights in North Carolina, it became apparent that the higher-lying Dayton caused a certain loss of performance resulting in their choice to make use of a catapult launch.

become a reality until after the Second World War. Aircraft managed speeds of just 70 km/h in those days – with the minimal flight speed not being much lower – and therefore flying was not yet seen as a practical proposition.

Scientific progress

Until around 1910 aviation remained limited to the successes of experimenting pioneers, whereafter engineers and scientists took the leading roles in further development. Even though they would not become pilots themselves, their research formed the basis on which continuously more efficient aircraft were built. Especially the developments in prediction methods for lift and drag forces on wings in combination with the use of wind tunnel measurements and the much improved engine technology led to predictability of aircraft performance levels becoming the norm. Still there were only a few who could be considered really knowledgeable. Among them were the English engineer *Frederick Lanchester* (1868–1946) and the German scientist *Ludwig Prandtl* (1875–1953). Both offered, independently from each other, explicating derivations of the foundations of flight physics.

Lanchester had experimented with plane models since 1890 and presented a theory in 1892 which formed a highly qualitative description of *circulating flow* around a wing, an essential element in the analysis of lift. Initially there was not much interest in his work, which led to him becoming discouraged and not publishing his research until 1907 in the book "Aerodynamics", followed a year later by "Aerodonetics". Unfortunately, even the experts had difficulties following his concepts and he therefore did not have much influence on general design practices. On the other hand, Prandtl's contribution was widely implemented in design methods through the introduction of the *boundary layer* concept (1904) and the well thought-out *lifting line* theory. The German *W.M. Kutta* (1867–1944) and the Russian *N.E. Joukowski* (1827–1921) also added important elements to wing aerofoil theories in the period 1902–1912. The Englishman *G.H. Bryan* (1864–1928) produced a sophisticated foundation for the *dynamic stability* analysis of aeroplanes in 1903.

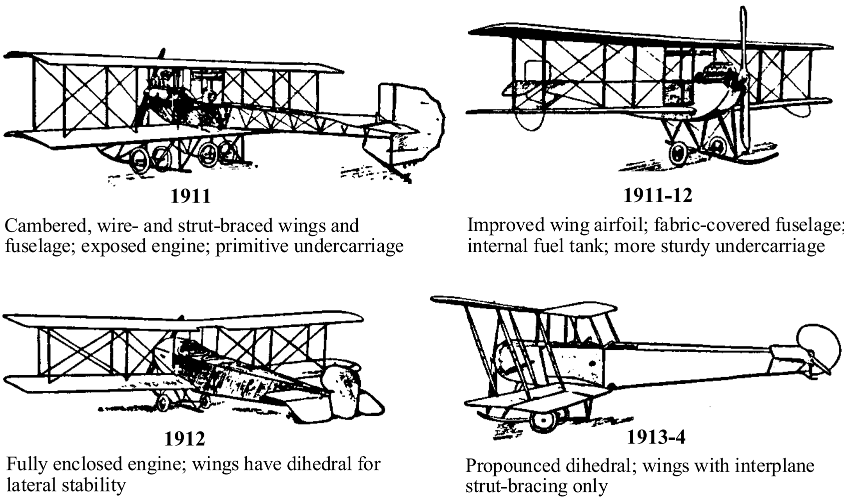


Figure 1.15 Appearance of aircraft prior to the First World War.

Aeroplanes becoming practical

France, Britain and Germany dominated aviation after 1910 until the 1920s which was mainly a result of the First World War. During this period many aircraft general arrangements were built that differed on essential elements from that of the Wright brothers. Most Europeans built braced *biplanes*, a construction which was mainly based on that of *L. Hargraves's* box-kite configuration (1894). The biplane proved to be the most suitable configuration at the time, taking into account the materials used: mild steal tubes, bamboo struts, fabric covering and bracing wires. Therefore, the biplane remained the main configuration for a considerable time, although some designers, such as Blériot and Levavasseur, chose to construct *monoplanes*, whereas *triplanes* were the exception. Biplanes remained widely accepted because of their lightness, though their structure was refined in such a way that the supporting bracing wires were unnecessary and wings were eventually supported by interplane struts (Figure 1.15), resulting in greatly reduced air drag. The first wings were generally primitive and consisted of a number of cambered sticks covered by fabric. These were joined by nose and rear beams on the Wright Flyer. Due to the wing being just a few centimetres thick, supporting ties were needed for further stiffening. Eventually aerodynamic research led to aerofoils that were much improved to become efficient cambered sections with adequate *thickness*, while also being able to offer sufficient lift and

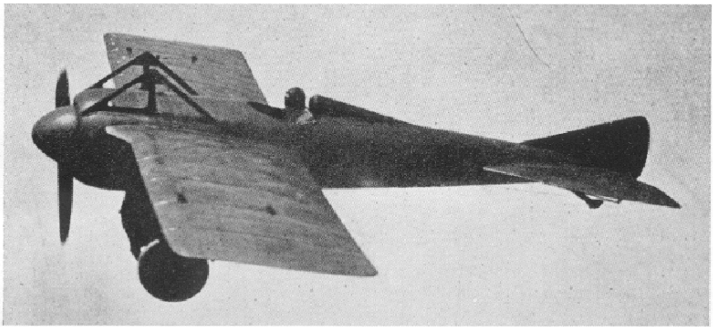


Figure 1.16 The first monococque aeroplane, Bécherau's monoplane Deperdussin (1912).

low drag. This allowed the wings to be internally supported, causing external supports and wires to become superfluous. Following further development, the *cantilevered wing* would eventually become the standard.

The Frenchman Bécherau was in 1912 the first to construct a fuselage *shell structure* – regarding the analogy of an egg shell this is also known as a (semi-)monococque construction – by which the stiff skin takes the loads rather than a fabric or triplex covered structure. His monoplane Deperdussin (Figure 1.16) obtained a speed of 174 km/h in 1912 and even exceeded 200 km/h in 1913. Inadequate engine technology had been the main reason for powered flight failing to develop as quickly as it could. The invention of the *Otto engine* meant a breakthrough, though aircraft initially suffered from a lack of power. Since they used *liquid cooling* systems their mass of approximately 5 or 6 kg/kW remained very much on the heavy side. In 1908 the brothers L. and G. Seguin invented the Gnome air-cooled *rotary engine*, which reversed their fortunes along with further *propeller* development.[16]

During the period from 1910 through 1914 many new planes of varying types were built, single-engined as well as multi-engined aeroplanes. The Russian *Igor Sikorsky* (1889–1972) astonished many in 1913 when he built the large four-engined Bolshoi after failed attempts to achieve flight with a rotorcraft. The Frenchman H. Fabre and the American G. Curtiss were the first to construct *hydroplanes* and perform risky overwater and Alp-crossing flights. Except purely for passenger transport, aircraft were also used for night, mail and long-distance flights, as well as for *parachute* jumps, aerobatics, radio-communications and for military purposes in particular. Air forces were formed with various tasks, such as surveillance and reconnais-

[16] The technology developments of engines and propellers will be discussed in Chapter 5.

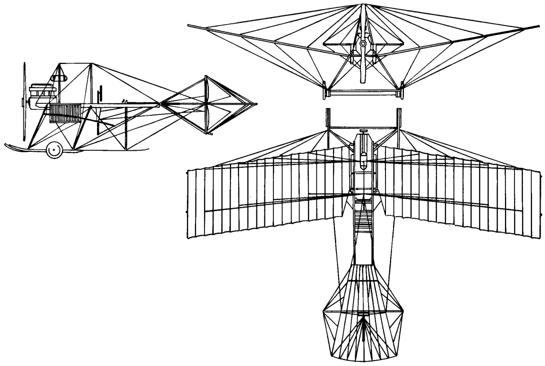


Figure 1.17 An early version of Anthony Fokker's first aircraft, the Spider (1911).

sance flights, artillery scouting, air raids and ship deck landings. The scout planes during the first World War were equipped with machine guns, so as to be able to dog-fight the enemy. These later developed into the first fighter planes and these have helped the general development of aviation, apart from conducting war.

Industrial development

One of the first to construct an aeroplane in the Netherlands was F. Koolhoven (1886–1946) who in 1911 – with the help of his assistant – built the FK-1 plane, an externally braced biplane powered by a 40 kW Gnome rotary engine. In the same year, *Anthony Fokker* (1890-1939) built his first aeroplane, the Spider (Figure 1.17). This was a stable monoplane with a high centre of gravity location, a wing with pronounced *dihedral* and a lateral control using wing-warping. Fokker taught himself to fly and rapidly became a competent pilot, giving numerous demonstrations of his planes to customers. However, there was not much interest in the Netherlands in buying his products, therefore he moved to Germany where he founded a factory in Berlin. Fokker was assisted by his chief engineer *Reinhold Platz* (1886–1966), a leading designer of renowned fighting planes such as the Fokker D3, the Dr1 and the D7.[17] Following these was the monoplane E1, which was equipped with a synchronized machine gun, which could shoot through the propeller plane, an invention that gave the Germans a great advantage. The Fokker Dr1 triplane was known as one of the best manoeuvrable aircraft at the time and

[17] "D" indicates a biplane and "Dr" a triplane.

one was flown by the famous fighter pilot Manfred von Richthofen (the "Red Baron"). The D7 (1918) is widely seen as the best fighting plane of the First World War due to its superior *manoeuvrability* and ability to climb steeply. Its successor, the D8, had a cantilevered triplex wing and could make 200 km/h with its 105 kW rotary engine. This *high-wing aeroplane* would later become the predecessor to Fokker's commercial aircraft, though the plane itself never played a roll in the war since a cease-fire had already been agreed by the time it was ready.

After the war, thousands of planes were built and the aviation industry took a giant leap forward. During the 1910s the following aircraft manufacturers were of significance:

Great Britain: A.V. Roe, the Royal Aircraft Factory at Farnborough, Short Brothers, de Havilland, Vickers, Fairey, Bristol, Sopwith, Armstrong Whitworth and Handley-Page.
France: Blériot, Farman, Morane-Saulnier, Bréguet and Voisin.
Germany: Albatros, Pfaltz, Halberstadt, Junkers, Dornier, Zeppelin and Fokker.
USA: Curtiss, Martin, Boeing (founded in 1916) and Vought.

Many of these manufacturers continued after the First World War and promptly made the switch to commercial aviation.

During the war, the average aircraft engine power grew from approximately 50 to 75 kW, up to about 300 kW at the end of the war. This resulted in the air speed rising from typically 120 to 200 km/h, while an altitude of 6,000 m became possible. Large bombers were built with the capability of carrying thousands of kilograms of lethal bombs, with which devastation was ravished. A major structural improvement was the use of light-weight metal aircraft with cantilevered wings, such as those designed by the German *Hugo Junkers* (1859–1935). For years he used the structurally efficient (but draggy) metal skins with corrugations running fore and aft and *Claudius Dornier* used a similar method for his large bombers. In 1919, A.K. Rohrbach introduced the *stressed skin* for wing and tail structures. These were (externally) smooth metal plates with internal stiffeners and stabilizing ribs in the direction of the flow. This structural concept would play a key role in revolutionizing the American aviation industry from the 1930s onward.

1.7 Aviation between the world wars

Foundation of laboratories

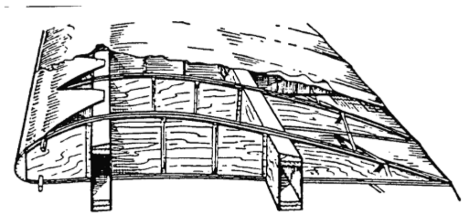
The formation of research institutes in various countries in fundamental, applied, as well as experimental research, had a profound effect on aircraft development. In this activity the scientists *Ludwig Prandtl* (1875–1953) and *Theodore von Kármán*[18] (1881–1963), who performed innovative research in their laboratory in Göttingen, had great influence. Initially the Americans trailed Europe in the advancement of aviation development, until they decided to found the National Advisory Committee for Aeronautics (NACA) in 1915, which would make a definitive impact on further technological development after the opening of the first laboratory in 1917. This renowned institute, which would become the National Aeronautics and Space Administration (NASA) in 1958 with the increased interest in aerospace, remains a world leader up to this day. Especially the development of *wing sections*– the well-known NACA 4- and 5-digit and the 6-series sections have been widely applied – have greatly contributed to the worldwide development in aviation, thanks to the general publication of their aerodynamic characteristics.

Commercial aviation in Europe

In 1919 Dutch pioneer *Albert Plesman* (1889–1963) founded KLM, the Royal Dutch Airline. Thanks to the Fokker-built commercial aircraft and later the Douglas DC-2 and DC-3, KLM would grow to be an important airline before the Second World War and presently the oldest airline still operating under its original name. A solid organization and a number of spectacular flights, like those to the Dutch Indies and the Melbourne air race in 1934, contributed to KLM's success.

Directly after the First World War, aircraft manufacturers concentrated on the construction of commercial aircraft in the form of modified bombers. However, it quickly became apparent that another approach was needed, concentrating on specific elements of passenger transport – reliability, lifespan, safety and comfort. The first such plane to be designed was the English built Koolhoven FK26 (four passengers in an enclosed cabin and the pilot in an open-air wooden construction), the first metal commercial aircraft was the

[18] Hungarian born Von Kármán emigrated to the USA in 1930, became a professor at the California Institute of Technology and took American nationality in 1936.



(a) Fokker's cantilever wing structure

(b) The three-engined F VIIB transport (1952)

Figure 1.18 Illustrations of the Fokker commercial aircraft from the 1920s.

Junkers F13 (five passengers, high wing, with a skin of dural corrugated plating).

A most successful development was initiated by *Anthony Fokker* in 1919 in the Netherlands with his model F2 (five passengers, high wing, compound metal and wood structure) which led him to becoming a leading manufacturer in the following fifteen years. His chief designer Reinhold Platz designed internally stiffened cantilever wooden wing structures, Figure 1.18(a), which proved to be aerodynamically very efficient. Manufacturer Fokker saw a chance to introduce a wide range of new aircraft to the aviation market during the period 1918–1936. Due to their good reputation as reliable aircraft, there was great demand for them from airlines all over the world. Well-known types were the single-engined F7a, the three-engined F7b, see Figure 1.18(b), the F12 and the F18. Fokker continued to use the high wing configuration with cantilever wooden wings and steal tubed fuselage with fabric or triplex covering. The engines were *air cooled radial engines* and the undercarriage was non-retractable. Fokker's main competitors were the metal *low-wing aircraft* of Junkers – especially the Junkers G-31 (1926) was a successful type – and later the American Ford 4-AT en 5-AT. The Ford

planes were similar to the Fokker F7b, but just as the Junkers were built of metal. Contrary to these types, the English manufacturer Handley Page had the slogan “slow but sure” for their aging biplanes, such as the well-known HP-42 for 38 passengers.

Fokker saw the sales of his aircraft recede around 1930 mainly due to the economic crisis. Furthermore, a revolution was taking place in aircraft development in the USA in 1934 with Boeing and Douglas starting to offer metal aircraft, equipped with a *shell structure*. Although Fokker obtained the rights to sell Douglas aircraft in Europe, the dominance of his industry was broken. After his death in 1939, the Fokker factories were destroyed during the Second World War.

American commercial aircraft

Initially the development of American air transportation lagged behind the expansion of European airlines. However, the pioneering flight by *Charles A. Lindberg* (1902–1974) – in 1927 he flew in 33.5 hours solo across the Atlantic Ocean from New York to Paris in the Ryan Spirit of St. Louis (Figure 1.19a) – as well as R.E. Byrd’s flights over both the North and South poles ignited great interest in commercial aviation. Additionally intensive research in the laboratories and various new inventions and developments elsewhere led to the modernization of commercial aircraft. These factors played a prominent roll in the suddenly increasing number of new aircraft manufacturers in the USA. After reshuffling around 1930, a select few larger manufacturers remained, such as Boeing, Douglas, Glenn Martin and Lockheed.

The predecessor of the modern commercial aircraft was the revolutionary six- or eight-person Lockheed Vega (1927) with its wooden structure and a *stressed skin* as a construction principle. The wing was cantilevered and the fuselage was a shell produced in two molds, resulting in a *streamlined* low-drag shape (Figure 1.19b). The record-breaking flights in 1932 by Amalia Earhart – like her non-stop transatlantic and cross-continental North-American flights – caught the imagination of many. The later version, the Vega 5B Winnie Mae, allowed W. Post and H. Gattey to be the first to fly around the world in 1931, with Post making the same journey on his own in 1933. The Vega had a non-retractable undercarriage with streamline caps, later versions of the Winnie Mae used for business trips had a detachable gear which would fall away after take-off and the plane would land on the

(a) The Ryan monoplane “Spirit of St. Louis” in which Charles Lindbergh made the first solo Atlantic crossing (1927)

(b) The Lockheed Vega transport (1927)

Figure 1.19 Aircraft that stimulated the development of aviation in the USA.

Figure 1.20 The Douglas DC-2, predecessor of the famous DC-3 airliner. The depicted aircraft is a replica of KLM’s Uiver which in 1934 won the London-to-Melbourne race in the handicap section.

reinforced fuselage belly. It was equipped with a turbo-charged radial engine which allowed it to fly at 9,000 m altitude and at a speed of 450 km/h over the American continent.

The modern commercial aeroplane was born in 1933 in the form of the Boeing 247 and the Douglas DC-1, followed a year later by the Lockheed

Electra. Various new innovations were implemented in these three aircraft as a result of research and construction developments:

- practically a complete lightweight metal construction, with the aluminium alloy Duralumin (Dural) as the dominant application,
- a cantilevered wing with a *stressed skin*,
- a fuselage executed as a semi-monococque shell structure,
- retractable flaps at the wing *trailing edge* for high lift at low speed,
- two – and later in certain types also four – air-cooled radial engines enclosed by NACA-developed streamline cowlings, suspended on the wing leading edge,
- *constant-speed propellers*, with high efficiency at any speed and
- a retractable undercarriage.

Stressed skin structures had become a reality thanks to the the investigations since 1925 by H. Wagner – he was working for the Rohrbach company in Germany – and to the famous designer *Jack Northrop* in the US (1928). They had worked independently, but came up with similar practical concepts. The development of wing flaps began in 1919 when the Englishman *F. Handley Page* invented the slotted *slat* at the wing *leading edge* which postpones *stalling* to a higher *angle of attack*. Because a fixed slot in the wing leads to a drag increment during the whole flight, this concept was only implemented in slower aircraft.[19] *Orville Wright*, together with J.M. Jacobs, invented the *split flap* in 1920, a downwards rotating segment under the fixed *trailing edge*. Further development would lead to the more effective *slotted flaps*, which allowed for a smaller *wing area*, allowing a reduction of aeroplane weight as well as drag (with retracted devices).

The 12-passenger DC-1 was replaced in 1934 by the larger production version, the DC-2 (Figure 1.20) for 14 passengers and in 1935 by the 21 passenger DC-3 Dakota. The Douglas Dakota was one of the most used aircraft around the time of the Second World War – until 1945 some 13,000 were built, including the military C-47 version. The four-engined Boeing 307 Stratoliner was developed in 1938, shortly followed by the Douglas DC-4. Both types were equipped with a *pressure cabin*, which allowed the aircraft to fly at high altitudes and therefore “above the weather”. In Germany, similar types were constructed, such as the Focke-Wulf FW 200 Condor and the Junkers Ju 90. This proved that the commercial *propeller aircraft* with *piston engines* were in definitive growth. In the 1930s many types of *seaplanes* were built for long-distance transport over water. Well-known types

[19] The *slats* used in modern airliners and business jets create a slot in extended position, but are retracted after take-off to reduce drag.

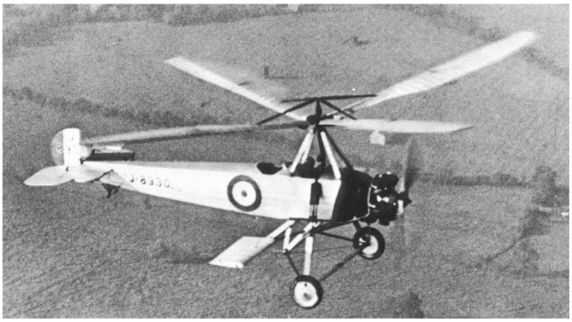
are the Dornier Do X (160 passengers), dating from 1930 and the Boeing Clipper (70 passengers), with both performing regular cross-ocean flights. They became obsolete after the war, when many airfields were constructed for regular air transport.

Rotorcraft

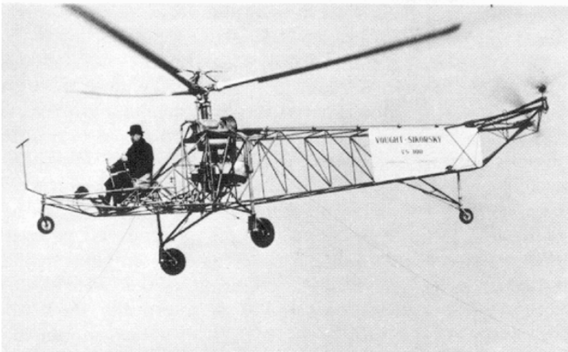
Although the Frenchman Paul Cornu performed the first (very brief) flight in a primitive *rotorcraft* in 1907, it took a few decades until one could speak of the first practical flight. The Spaniard *Juan de la Cierva* (1895–1936) is accredited with a large contribution to the development of this alternative direction in aviation. Around 1920 he thought of an idea to replace the fixed aeroplane wing with a freely rotating, air-driven, horizontal *rotor*, which gains lift from forward speed. Air drag must be overcome by a propulsive device, usually a propeller. With this discovery came the invention of the *autogiro*, an intermediate step between fixed-winged flight and the *helicopter*. An autogiro has the possibility to land vertically, but because rotor momentum is needed for lifting off, a purely vertical take-off is not possible. The first flight by de la Cierva's autogiro took place in 1923, Figure 1.21(a), ten years later he made jump starts by linking the rotor to the engine axis.

It quickly became apparent that the main difficulty of the helicopter rotor was a *rolling moment* occurring at forward speed. This is a result of the increased lift on an advancing blade, while a retreating blade has reduced lift. Initially, de la Cierva solved this problem by implementing two opposite turning rotors. Later he had the bright idea of building a *flapping hinge* into the rotor, leading to the advancing blade tipping upwards and thereby reducing the angle of attack, while the retreating blade will tip downwards. This fundamentally sound solution for the rolling problem is used in just about all helicopters and (incidentally built) autogiros these days. During the 1920s a great effort was made to make the helicopter a stable and manoeuvrable vehicle. One major difficulty was the *reaction torque* due to driving the rotor, caused by the moment exerted by the main rotor on the helicopter's body, moving it in an opposite direction to the rotor.[20] The then common solution was to have two opposite rotors, cancelling out each other's moment.

[20] The autogiro does not suffer from this difficulty because the rotor is not engine-powered.



(a) De la Cierva's first autogiro (1923)



(b) The first practical helicopter with a single lifting rotor, the Sikorsky VS-300 (1941/42)

Figure 1.21 The first *helicopters*.

Dutch rotorcraft pioneer *A.G. Von Baumhauer*[21] (1891–1939) was one of the first to perform experiments with single rotors and cyclical adjustable blades (patented in 1920). To compensate for the reaction moment of the main rotor, Von Baumhauer used a vertical *tail rotor* powered by a separate engine. Since both rotors were not linked to the same engine there were control difficulties. Test flights were performed between 1925 and 1930 with the helicopter only ascending a few metres above the ground as it was stabilized by hanging chains. During these tests there were many problems caused by rotor vibrations, leading on one occasion to serious damage caused by a fatigue fracture of the support-arm to the rotor axis.

[21] Von Baumhauer was vice-president of the former (Dutch) National Research Institute for Aviation founded in 1921, presently the National Aerospace Laboratory, NLR.

It was not until the 1930s that the helicopter had developed sufficiently to be a practical aircraft. Frenchmen L. Bréguet and R. Dorand were the first to build a successful helicopter. Their co-axial rotorcraft performed its first flight in 1935. In the years following the helicopter achieved a top speed of 108 km/h and reached an altitude of 600 m. This was promptly followed by successful flights by the Focke Achgelis Fa-61. This aircraft was equipped with two rotors on either side of the body and was easy to manoeuvre, though this concept was rarely used thereafter. Both of these helicopters made use of rotor blades with hinges for blade flapping, lagging and pitch control. With the construction of the VS-300 in 1940 by the American immigrant *Igor Sikorsky*, the standard for the helicopter was set. After over a year of experimenting, the VS-300 became a success; see Figure 1.21(b). Sikorsky's concept made use of

- a single main rotor with a *cyclic pitch* control for manoeuvring by controlling the direction of the rotor lift,
- *flapping hinges* to negate the rotor's rolling moment,
- a vertical *tail rotor* for directional control and for counteracting the main rotor couple.

Airships

As early as 1900 the German industrialist *Count von Zeppelin* (1838–1917) started with the fabrication of rigid airships, featuring a metal lattice framework for stiffening. Regular flights were carried out before the First World War, offering many passengers the chance for their maiden flight. These airships were new and intriguing and from that moment the manufacturer's name would become so famous that (rigid) airships are still called "Zeppelins". Airships managed to compete with winged commercial aircraft between the wars. The Graf Zeppelin, the best-known airship of the time, carried some 13,000 people during approximately 16,000 flying hours between 1928 and 1937. Among its flights were some 140 transatlantic flights and a flight around the world in 1929. The English-built R 100 airship, with an Aluminium alloy stiffened hull, also became well known, but the improved R 101 crashed during its maiden voyage to India. The introduction of much faster commercial aircraft, a number of tragic accidents – including the well-known footage of the burning Hindenburg (1937) – and the start of the Second World War were the main reasons that airship activities came to an end. Although man's first venture into the skies was in a balloon and many consid-

ered the airship as the right answer for mass air transport, lighter-than-air aviation did not significantly develop after 1940 and its use was limited to scientific research, recreational ballooning, long-distance experimental flights and advertisement.

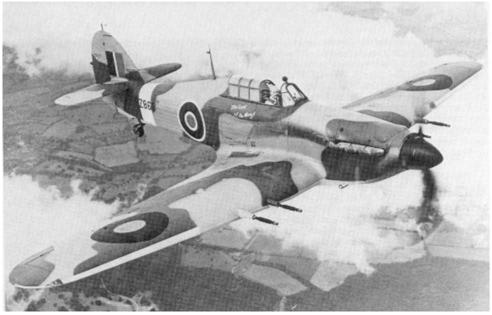
1.8 Development after 1940

The beginning of the Second World War ended the pioneering era of aviation, with the main ingredients at hand for the stormy developments that would follow. Especially, the introduction of the gas turbine based *jet engine* led to an important evolution from propeller to *jet propulsion*. Despite this revolution, the propeller-powered aeroplane has still not been eliminated, as many continue to be applied in regional and general aviation.

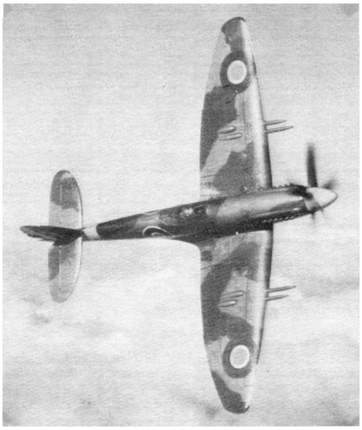
Fighters and experimental aircraft

From the 1920s onward, much knowledge was collected on high-speed flight through activities such as air races with seaplanes, especially the Schneider Trophy races (1913–1931). The fastest speeds until 1935 remained limited to 350 to 400 km/h – only racing planes were faster –, during and immediately after the war, speeds nearing the *velocity of sound* were within reach. Between 1935 and 1945 many fast and agile propeller fighter planes were built, such as the the German Messerschmitt Me 109 and the Focke-Wulf Fw 190, the English Hawker Hurricane and the legendary Supermarine Spitfire, the American North American P-51 Mustang and the Republic P-47 Thunderbolt (Figure 1.22). Some of these planes could reach speeds of 800 km/h and altitudes of 12,000 m, performances that were made possible by *piston engines* with over 1,500 kW of power. These aircraft were of the utmost importance during the Second World War.

In Chapter 5 attention will be paid to the early developments of *jet propulsion*, for which several applications were suggested as early as the 18th and 19th centuries. The Frenchman Henri Coanda exhibited a biplane in 1910 with a *ducted fan* – though it was never flown – and in 1913 the Frenchman René Lorin patented his aero-thermodynamic duct (“athodyd”). These would be early examples of the later introduced *ramjet engine*. However, Lorin’s attempts to realize the device were hampered by a lack of heat resistant materials. The ramjet engine is particulary suited for (supersonic) high

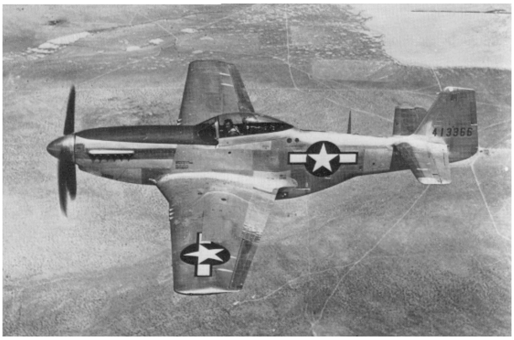


Hawker Hurricane



Supermarine Spitfire

Messerschmitt Me109



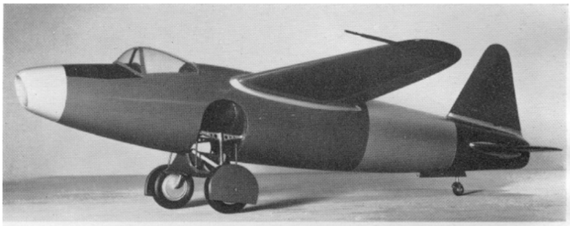
North American P-51 Mustang

Figure 1.22 Well-known fighters of the Second World War.

speeds (Chapter 9). The Frenchman *R. Leduc* built a few experimental planes with ramjet engines in the 1950s.

The German scientist *Hans Joachim Pabst von Ohain* (1911–1998) worked from 1930 onwards on a *turbojet engine*. It was installed in the Heinkel He 178 in 1939, which would become the first *jet aircraft* to fly in history[22] (Figure 1.23a). The first English-built jet aeroplane, the Gloster E28/39, flew in 1941 and was equipped with a turbojet engine de-

[22] In 1928 there had already been some glider flights performed with rocket engines, involving industrialist F. von Opel and aerodynamicist A. Lippisch.



(a) The first jet aircraft in the history, the Heinkel He 178 (1939)

(b) The first British jet aircraft, the Gloster E28/39 (1941)

Figure 1.23 The first experimental jet aircraft.

signed by *Frank Whittle* (1907–1996); see Figure 1.23(b). Neither aircraft were designed as fighting planes, but merely to demonstrate the new engines.

Initially jet planes failed to offer spectacular levels of performance, even though the first one built in series production, the Messerschmitt Me 262, achieved 840 km/h. Due to the fact that jet engines maintain their *thrust* at high speeds, it soon became clear that appropriately designed jet aircraft might be able to perform *supersonic* flight, that is, faster than the *velocity of sound*. The first aircraft to pass this speed in horizontal flight was the experimental Bell X-1 (Figure 1.24) using *rocket propulsion*, though from 1950 jet-propelled fighters would regularly make this achievement; see Figure 1.25(a). Less than a decade later several fighter planes achieved twice the speed of sound at high altitude, among these were the English Electric P1 Lightning, the Lockheed F-104 Starfighter and the MiG-21, all developed in the 1950s. Modern fighters, such as the General Dynamics F-16 Fighting Falcon, the McDonnell Douglas F/A 18 Hornet, the Lockheed F-22 Raptor, the Dassault Rafale, the SAAB Gripen and the Eurofighter Typhoon, have similar top speeds. For military jet aircraft without *afterburners*, the altitude limit is approximately 16,000 m. There are exceptions to this – the Lockheed U-2R (R for reconnaissance) regularly flew at altitudes of up to

Figure 1.24 The Bell X-1, the first aeroplane to exceed the speed of sound, on October 14th, 1947.

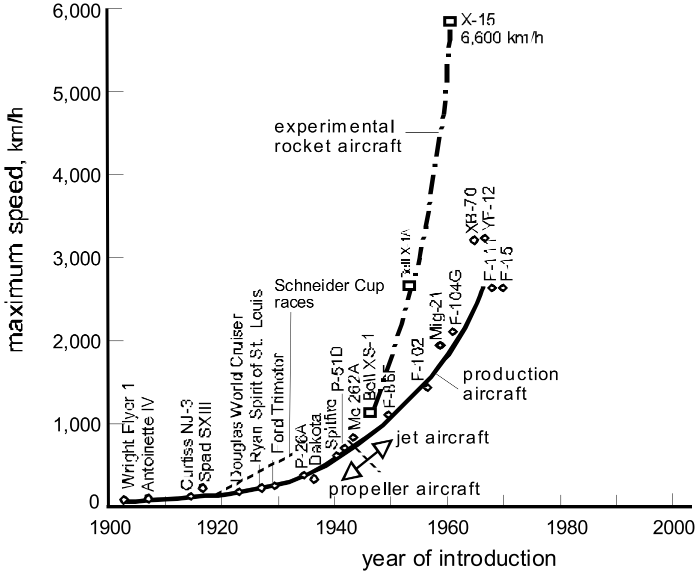
23,500 m and the Lockheed SR-71A even achieved an altitude of 26,000 m in 1971 at almost 3,500 km/h, more than three times the velocity of sound.

Experimental aircraft with rocket propulsion have further pushed the limits of speed and altitude. The North American X-15 achieved 7,300 km/h while flying in the *stratosphere* in 1967, equivalent to 6.72 times the velocity of sound. In 1963, the X-15 performed a flight at a maximum altitude of 108 km, though because the majority of this nearly ballistic flight was performed in extremely thin air, this could hardly be called aviation. With the first real spaceflight in 1961, when the Russian Youri Gagarin became the first man in space, all velocity and altitude limits were surpassed.

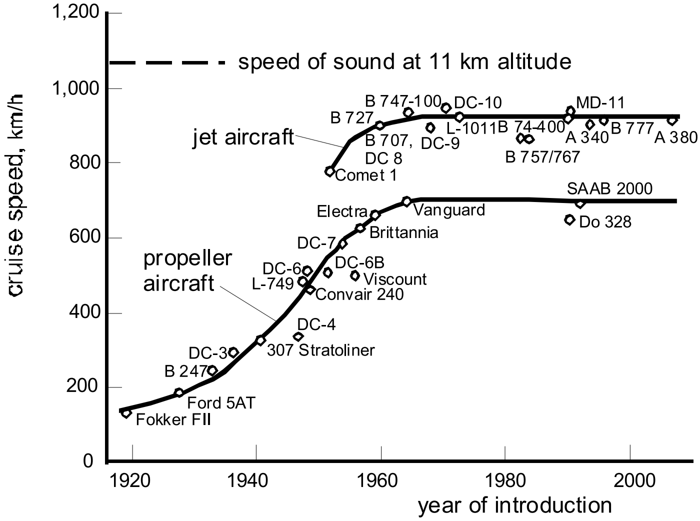
Commercial aircraft

After the Second War World, many advancements made by military aviation were implemented in commercial aviation. The USA had a head start on Europe and therefore the stronger position to dominate the market. Large *propeller aircraft* with piston engines, such as the Lockheed Constellation and the Douglas DC-6, were introduced in 1946. Both had a *cruise speed* of approximately 500 km/h; see Figure 1.25(b). Especially, the DC-6 was an economical aircraft and later types, such as the DC-7, were derived from it. The Super Constellation and the DC-7C were equipped with turbo-compound piston engines, featuring exhaust-mounted turbines for the delivery of extra shaft power. These engines were economic on fuel consumption, but less reliable due to their high complexity. The last generation of piston-engine powered commercial aircraft reached cruise airspeeds of approximately 550 km/h.

Fuel-efficient *turboprop* aircraft raised the cruise speed to around 650 km/h in the 1950s. However, types such as the Bristol Brittannia, the



(a) military and experimental aircraft



(b) subsonic airliners

Figure 1.25 Historical development of the maximum flight speed.

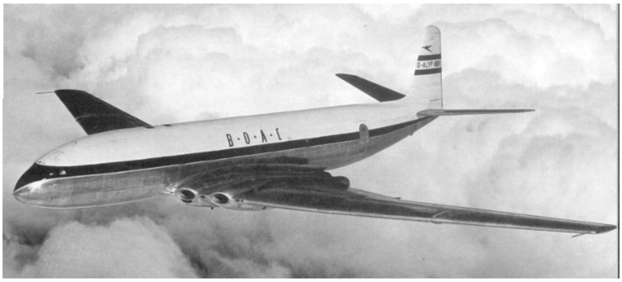


Figure 1.26 The first commercial jet aeroplane, the de Havilland DH 106 Comet Series 1.

Vickers Vanguard and the Lockheed Electra, were not produced in large numbers because they were unable to compete with the more comfortable and much faster jet airliners. Only smaller short-haul turboprop aircraft, such as the Vickers Viscount and the Fokker F-27, managed to survive in the market, later to be followed by more modern types.

The first operational commercial jet aeroplane, the De Havilland DH 106 Comet, made its maiden flight on July 27th, 1949. The first production version (Figure 1.26) was equipped with four de Havilland Ghost 50 Mk1 jet engines, buried inside the wing roots, which allowed the plane to fly at 790 km/h. This seemed to herald the start of the jet engine era. However, three out of the nine operational planes were lost in crashes. Two of the aircraft crashed due to metal fatigue, caused by the continuous compression and decompression of the *pressure cabin* , leading to structural failure at a highly stressed cabin window frame. The improved version Comet Series 4, with a cruise airspeed of 856 km/h, failed to compete with the successful Boeing 707 and Douglas DC-8 airliners. These were used for long-distance (transatlantic) flights, resulting in the definitive beginning of the jet propulsion era in commercial aviation around 1958/59.

Half way through the 1960s, the previously mentioned aircraft were complemented by a wide range of aircraft of varying sizes, for short (Boeing 727, 737, Douglas DC-9) as well as long-distance flights (Boeing 747, Douglas DC-10 and Lockheed L-1011), with a maximum cruise airspeed of around 900 km/h. The Boeing 747, Figure 1.27(a), designed in the late 1960s and further developed in the 1980s, was the first commercial aeroplane with a wide body (fuselage) with two passenger decks with two aisles each. This airliner was also the first to be equipped with high *by-pass ratio turbofan engines*, featuring reduced fuel consumption and noise production. The 747 continues to be the workhorse for long-distance flights in the early 21st cen-

(a) Boeing 747-100

(b) Airbus A380

Figure 1.27 The largest commercial jet aircraft (courtesy of *Flight International*).

tury. The 747-400 version has the capacity to carry some 420–524 passengers.

The dominance of Boeing in the commercial aircraft market grew in the 1980s and 1990s through the introduction of new 737 versions, the 757, 767 and 777 and a merge with the manufacturer McDonnell Douglas. The newly formed company consolidated a dominant position on the world market, with a wide range of aircraft for long and short distances and for 100 to 500 passengers. In 1972, the European Airbus A300 performed its first flight. The types A310, A320, A330 and A340 with various versions were developed later, offering serious European competition to Boeing aircraft for the dominant position in the airliner market. Around the turn of the centuries, Boeing and Airbus were equally successful and Airbus' position might even strengthen into the 21st century with the introduction of the ultra-large de A380, Figure 1.27(b), which has a capacity between 550 and 850 passengers.

The rebirth of the Dutch aircraft industry Fokker after the Second World War led to the development of commercial short-haul aircraft. The prototype of the Fokker F27 Friendship, a turboprop aircraft for 40 to 52 passengers, made its maiden flight in 1957 and became one of the most produced postwar commercial aircraft. The Fokker F28 Fellowship jet-powered short-haul airliner was developed in the early 1960s, with versions for 65 to 79 passengers. These two aircraft formed the baseline for modernized versions, such as the Fokker 50, the Fokker 100 and the Fokker 70 in the 1980s. When Fokker

Figure 1.28 The British Aerospace/Aerospatiale Concorde, the only supersonic commercial aircraft that served for a considerable period of time (courtesy of *Flight International*).

became insolvent and closed in 1996, it had produced 1,300 post-war commercial aircraft.

Modern *subsonic* airliners can fly over distances of 12,000 to 16,000 km without an intermediate stop, cruising at a speed of 800 to 1,000 km/h at altitudes between 9,000 and 12,000 m. The introduction of the turbofan engine has lead to a continuous growth of air transportation, both in terms of available connections and seat-miles produced. At the same time, air transportation has become increasingly reliable and safe.

One special type of airliner cannot go unmentioned, namely the *supersonic* British Aerospace/Aerospatiale Concorde (Figure 1.28), which cruised at about 2,000 km/h, that is, twice the *velocity of sound*. The first prototype of Concorde, the result of British/French cooperation, made its maiden flight in 1969. Development- and production versions followed in 1973 and from 1976 fourteen of these extremely fast and comfortable aircraft offered their expensive form of transport. Air France and British Airways operated Concordes mainly on North-Atlantic routes to and from the USA. Concorde represented an impressive technological achievement, with its small fleet putting more hours of supersonic flight than all military aircraft together. During Concorde's development, it was presumed that it could fly supersonically above land as well as oceans. However, the occurrence of the *sonic boom* meant that supersonic flight was admitted only for overwater flight, limiting the potential for supersonic air transport. *Engine noise* during take-off was much higher than is generally accepted by the public and the steep increase of kerosine prices during and after the second fuel crisis led to the aircraft failing to meet its economical expectations. In the year 2000 a Concorde crashed during taking off at le Bourget airport near Paris and a few years

later all Concordes were taken out service. Although research into the development of a successor has been carried out in the USA and Europe since 1980, it does not seem likely that it will be developed in the first decades of the 21st century. Contradictory to subsonic flight, the future of supersonic commercial aircraft remains very uncertain.

Bibliography

1. Anderson Jr., J.D., *The Airplane, A History of Its Technology*, American Institute of Aeronautics and Astronautics, Inc., Reston, VA, 2002.
2. Bayne, W.J. and D.S. Lopez (Editors), *The Jet Age*, Smithsonian National Air and Space Museum, Washington, DC, 1979.
3. Bilstein, R.E., *Flight in America 1900-1983*, The Johns Hopkins University Press, Baltimore, 1984.
4. Chaikin, A., *Air and Space, The National Air and Space Museum Story of Flight*, Smithsonian Institution in association with Bulfinch Press, Boston, 1997.
5. Chant, C., *Aviation, An Illustrated History*, Orbis Publishing, London, 1978.
6. Gibbs-Smith, G.H., *The Invention of the Aeroplane*, Taplinger Publishing Cy., New York, 1965.
7. Gibbs-Smith, G.H., *A Brief History of Flying, from Myth to Space Travel*, British Science Museum Booklets, London, 1967.
8. Gibbs-Smith, G.H., *Aviation, An Historical Survey, from Its Origins to the End of World War II*, Her Majesty's Stationary Office, London, 1970.
9. Green, W. and R. Cross, *The Jet Aircraft of the World*, Macdonald, London, 1955.
10. Gunston, B. (Editor), *Chronicle of Aviation*, Chronicle Communications Ltd., United Kingdom, 1992. Also: J.L. International Publishing Inc., USA, 1992.
11. Heppenheimer, T.A., *A Brief History of Flight, From Balloons to Mach 3 and beyond*, John Wiley & Sons, Inc., New York, 2001.
12. Loftin Jr, L.K., "Quest for Performance, The Evolution of Modern Aircraft", NASA SP-468, 1985.
13. Miler, J., *Lockheed's Skunk Works, The First Fifty Years*, Aerofax Inc., Arlington, TX, 1993.
14. Naylor, J.L. and E. Owen, *Aviation, Its Technical Development*, Vision Press, London, 1965.

15. Schatzberg, E,. *Wings of Wood, Wings of Metal, Culture and Technical Choice in American Airplane Materials*, Princeton University Press, 1999.

16. Taylor, J.W.R. and K. Munson, *History of Aviation*, New English Library, London, 1975.

17. Taylor, M.J.H. and D. Mondey, *Milestones of Flight*, Jane's Publishing Cy., London, 1983.

18. Toland, J., *The Great Dirigables, Their Triumphs and Disasters*, Dover Publications, Inc., New York, 1972.

19. Various authors, *Ein Jahrhundert Flugzeuge, Geschichte und Technik des Fliegens*, herausgegeben von Ludwig Bölkow, VDI Verlag, Düsseldorf, 1990.

20. Weyl, A.R., *Fokker: The Creative Years*, Putnam, London, 1965.

21. Whitford, R., *Evolution of the Airliner*, The Crowood Press, Ramsbury, England, 2007.

22. Wright, O., *How We Invented the Airplane*, (Editor F. Kelly), Dover Publications, Inc., New York, 1988.